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14. ABSTRACT
Analysis of the Shelfbreak PRIMER data sets are described. These data sets, consisting of primarily high-resolution hydrographic surveys, show important shelfbreak processes including interaction of a slope eddy with the front, large-amplitude frontal meandering, and frontal response to wind forcing. In addition, collaborative work with acousticians on acoustic propagation across the front is also described. In general, the front is shown to contain large horizontal and vertical velocity shears, leading to large day-to-day variability. In addition to analysis of these data sets, analysis of drifter tracks near the front have also shown new perspectives on exchange across the front, and a stability analysis of the front was also performed.

15. SUBJECT TERMS Shelfbreak frontal dynamics, Middle Atlantic Bight, SeaSoar Data, Shelfbreak PRIMER data sets, shelfbreak processes, acoustic propagation across the front, drifter tracks, high-resolution hydrographic surveys.

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Final Report

Shelfbreak Frontal Dynamics in the Middle Atlantic Bight: Analysis of the SeaSoar Data from the ONR Shelfbreak PRIMER Experiment

Grant number: N00014-98-1-0059

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Long-Term Goals

The long-term goal of this project was to understand shelfbreak frontal processes responsible for day-to-day variability of the shelfbreak front in the Middle Atlantic Bight. We also wished to understand how the frontal variability affected sound propagation between the continental slope and shelf.

Objectives

Our primary objective was to analyze data collected during the Shelfbreak PRIMER experiment. This experiment consisted of well-resolved hydrographic data from the WHOI SeaSoar. We wished to understand how processes such as baroclinic instability and frontal meandering affected alongshelf variations in the frontal structure. We also were interested in how motions over the upper continental slope might force the front. Another goal was to see how the synoptic sections compared with a climatological averaged front. In addition, we wanted to collaborate with acousticians so that our data could be used to produce three-dimensional soundspeed fields to study acoustic propagation near the shelfbreak.

Approach

We used the PRIMER data sets to study aspects of the alongfront variability, including alongfront accelerations and decelerations. Because the sampling strategy of the observations took into account both spatial and temporal decorrelation scales, we were able to obtain well-resolved three dimensional thermohaline and velocity fields.

In addition, in collaboration with Dr. M. Susan Lozier of Duke University, we also obtained drifter data for trajectories near the shelfbreak in this area.

Tasks Completed

We completed the analysis of the spring and summer Shelfbreak PRIMER data sets. Three-dimensional thermohaline and velocity fields were obtained and examined to investigate lateral and vertical velocity shears, temporal evolution of the front, and ageostrophic flows associated with curvature of the front. For the summer, we were also able to obtain estimates of cross-shelffluxes of heat, salt, and buoyancy. An order-of-magnitude estimate for vertical velocity was also obtained for the spring data set.

In addition, collaborative work on statistics of Lagrangian exchange within the front, and stability characteristics of the front were also completed. In collaboration with many of the acousticians in this program, we also completed several manuscripts on acoustic propagation within the front.

A climatology of the area was used to help plan the field program and to examine regional contrasts between the New England shelf, New Jersey shelf, and the south flank of Georges Bank (Linder and Gawarkiewicz, 1998; Figure 1). This enabled us to learn about the mean structure of the front as well as the seasonal shifts in the structure, most notably the difference between summer and winter conditions.

Results

The Shelfbreak PRIMER data set provided a very detailed view of the complexity of the three-dimensional structure of the shelfbreak front. During the spring, a small slope eddy was present immediately adjacent to the front. Flow offshore of the front was directed to the east, opposing the mean flow within the front. As a result of the onshore and offshore directed velocities on opposing sides of the front, there were significant differences in frontal structure over 30 km in the alongshelf direction. To the west of the anti-cyclonic eddy, there was a very sharp front with a strong frontal jet with maximum alongshelf velocities of 60 cm/s (Figure 2). To the east of the eddy, the front was much more diffuse and maximum velocities near the surface were only 20 cm/s. A manuscript on this work is in press in the Journal of Physical Oceanography (Gawarkiewicz *et al.*, 2001a).

During the summer, a large amplitude frontal meander propagated through the study area. The peak to trough amplitude of the meander (30 km) was comparable to the wavelength of the meander (40 km), indicative of the large curvature within the front and frontal jet. This lead to strong ageostrophic flows estimated to be as large as 20 cm/s. A particularly interesting aspect of the flow field was a small eddy of shelf water which appeared to be detaching from the front (Figure 3). This was accompanied by an offshore flux of fresh water from the shelf to the slope and contributed to a net buoyancy flux offshore which was larger than the one previous synoptic estimate. A manuscript on this is in preparation and will be submitted shortly (Gawarkiewicz *et al.*, 2001b). In general, an important result from these two studies is that there is a high degree of non-linearity in the dynamics of the front, in that advection is quite important in the temporal variability.

The variability of the frontal jet also has important effects on the day to day changes in high-frequency processes present near the shelfbreak. Colosi *et al.* (2001) examined the internal tides within the PRIMER study area and found that the initially linear internal tide evolved quite rapidly into a train of shoreward propagating internal solitary waves. The timing and amplitude of the internal solitary waves were strongly affected by the onshore and offshore velocity components of the frontal jet as it changed its orientation within frontal meanders.

A stability analysis of a shelfbreak front was completed (Lozier *et al.*, 2001). The model suggested that e-folding time scales for growth were as short as one day for maximum jet velocities comparable to those in the PRIMER observations. Analysis of drifter trajectories (Lozier and Gawarkiewicz, 2001) suggest that the front can be thought of as a "leaky pipe", with some flow extending along the front between Georges Bank and Cape Hatteras, but with frequent losses to the continental slope regions.

The implications of the frontal structure for acoustic propagation were reported in Lynch *et al.* (2001). A particularly important aspect of the front was the presence of a warm, saline layer of slope water near the bottom. This layer resulted in upward refraction of sound, thus reducing the effects of bottom attenuation. Analysis of oceanographic conditions for a shelfbreak front off the east coast of Korea and its effects on acoustic propagation was also completed (Abbot *et al.*, 2001).

In addition, Gawarkiewicz co-advised two students, a Master's student and a Doctoral student, with Dr. James F. Lynch (C. Linder and B. Sperry, respectively).

Impact for Science

There have been a number of general results from this project which we believe will have applicability to a number of other shelfbreak regions. First of all, the observations clearly show in a variety of seasons that mesoscale variability over the continental slope contributes to a great deal of frontal variability. Eddy scales were smaller than that of warm core rings, suggesting a wider range of length scales for slope eddies than previously reported. Second, there appears to be large relative vorticities within the front, at times comparable to the Coriolis parameter. This is indicative of non-linear dynamics within the front, along with high growth rates for instabilities. Third, the presence of the warm near-bottom layer of slope water leads to shielding of the bottom for sound propagation and reduced bottom attenuation. This has important implications for possible detection and evasion tactics within the frontal region for naval vessels.

Relationships to Other Programs

Much of the experience from this program was directly incorporated into the planning of the ASIAEX field program in the South China Sea. This is also a joint shallow water acoustics/physical oceanography program, which also has numerous international participants. The Shelfbreak PRIMER data sets are being actively used in the DRI "Capturing Uncertainty in the Tactical Environment". The data sets are also being used within the DRI "Effects of Sound in the Marine Environment" in order to learn about the effects of Navy sonar systems on marine mammals.

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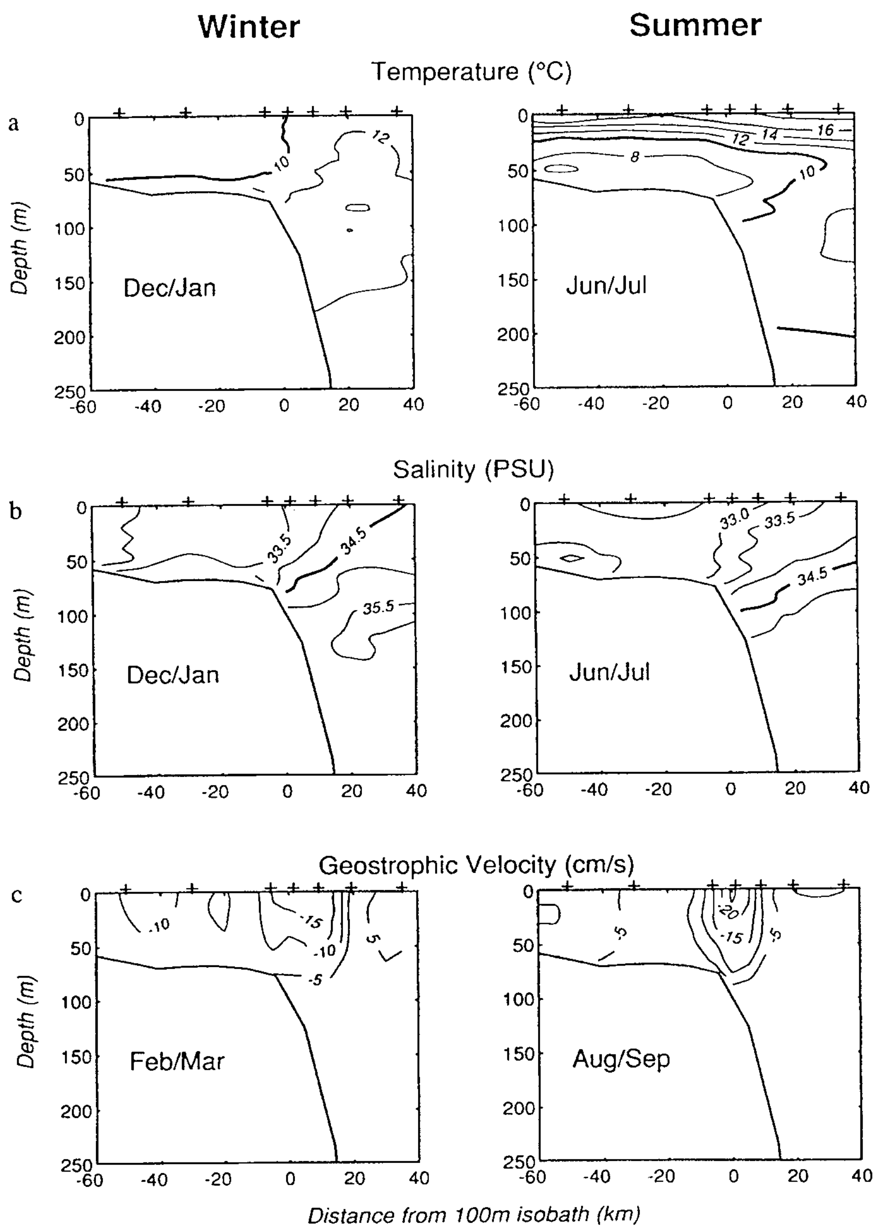

Figure 1. Climatological values of temperature, salinity, and geostrophic velocity for the shelfbreak front from Linder and Gawarkiewicz (1998).

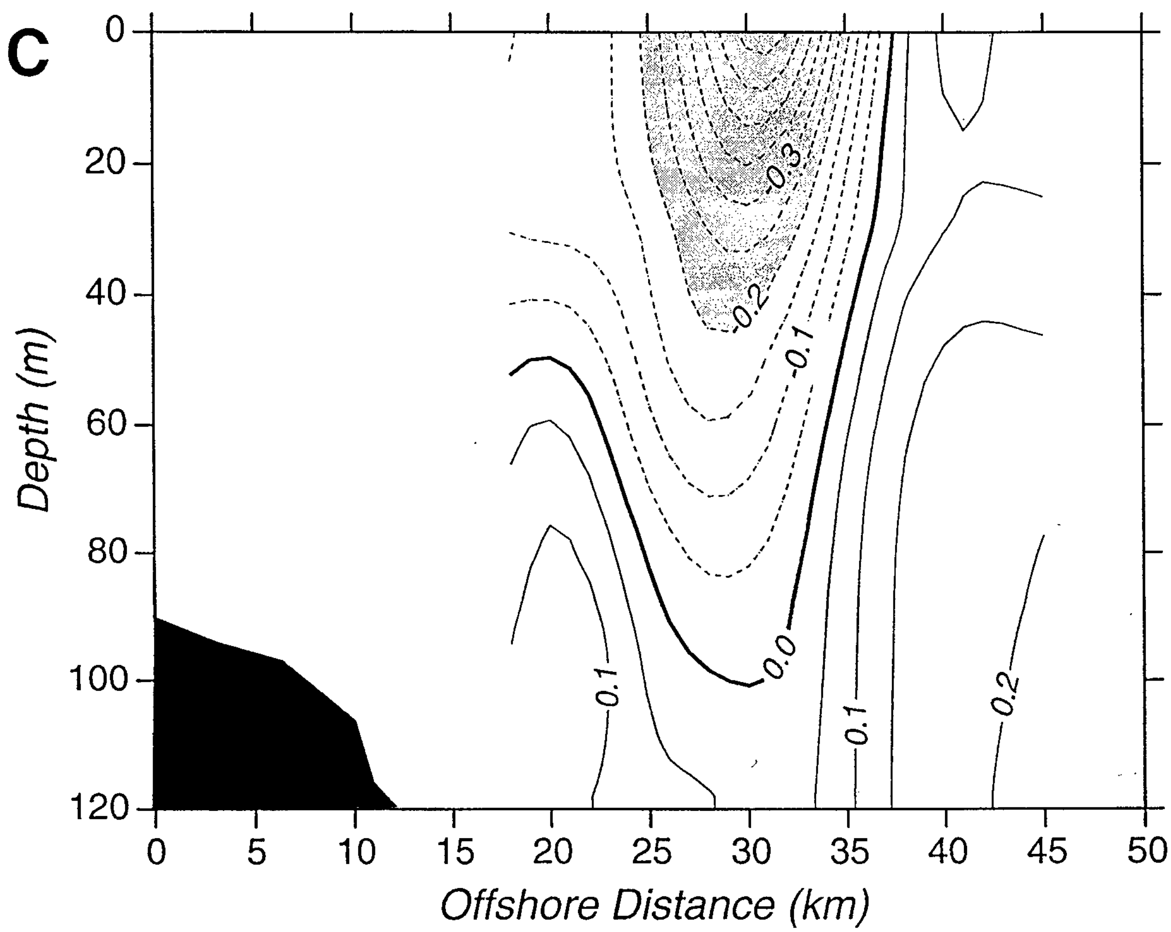

Figure 2. Geostrophic along-shelf velocity for the shelfbreak jet during spring, from Gawarkiewicz *et al.* (2001a).

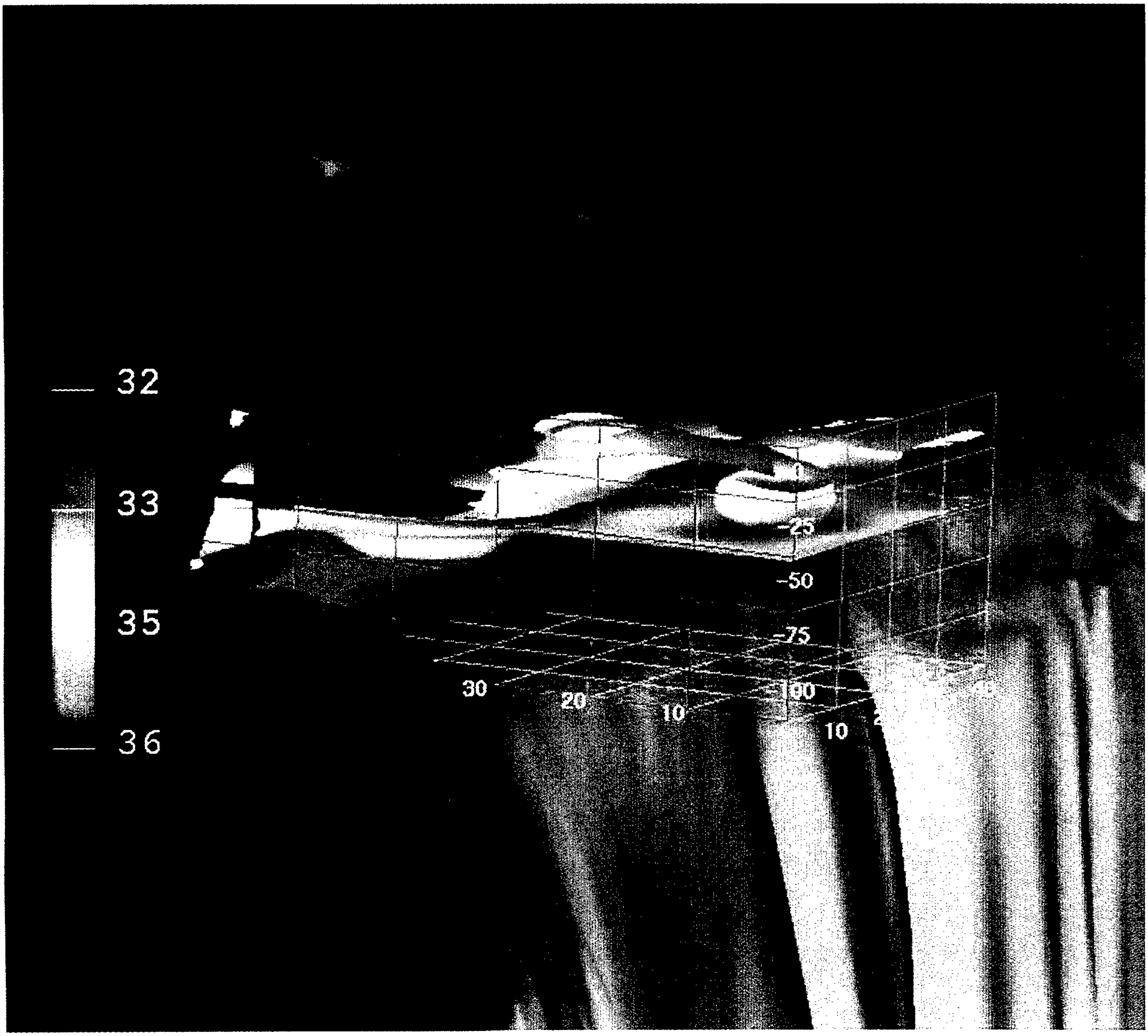

Figure 3. A three-dimensional view of a small eddy of shelf water (low salinity) detaching from the front during the summer (Gawarkiewicz et al., 2001b}.